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Bending of sheet metal of complicated shapes (for 90° angle and more) in combined tools

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Methodology of research

ABSTRACT

Purpose: Paper describes bending of sheet metal for angles greater than 90 degrees on simple forming tools. Bending using the bending method „traktrix" (in two steps) or the method „turning of the strip" (in one step) can be used for more complicated bends, i. e., for 90 degrees or more.
Design/methodology/approach: We used the principle of "traktrix" curve known in field of deep drawing process in bending process. The bending method, based on „traktrix" curve for more complicated bends, i. e., for 90o or more was developed. A sketch of 90o bending of unknown author and unknown source existed.
Findings: It's possible to bend sheet metal for 90 degrees or more using "traktrix" curve.
Research limitations/implications: The research was limited by time and costs. We carried out the research till we get the described product. Future research should be performed in field of parameters of bending tool.
Practical implications: We made only one version of each method, of course for practical reasons since we did not need different angles on one product. It would be appropriate to complement both methods in detail theoretically and by testing in the frame of a more comprehensive research work.
Originality/value: This article describes the original approach to bending of sheet metal for angles greater than 90 degrees. Movement of forming tool is carried out only in vertical direction and therefore savings by construction and manufacturing of bending tools are possible.
Keywords: Plastic forming; Tool-making; Sheet metal; Bending; Deep drawing

1. Introduction

In practice we often have to do with bending of sheet metal at right angle, i. e. 90°, and frequently even at angles exceeding 90°. From the theory it is known that in one step, with one sheet metal bending, it is difficult to reach these angles and impossible to reach the angles exceeding 90°. The spring back depends on each material individually; it amounts to 2° - 5° in case of materials mostly used for the component parts.

Thus, so far we have used the so called oscillating mandrel. By the use of the "oscillating mandrel" the required angle was reached in two steps. In the first step bending is effected by the bending mandrel and in the second step the bend is finalized by the "oscillating mandrel". The oscillating mandrel is "attached" to the tool top part a pin round which it oscillates by means of the slope and presses the product so that the required angle in reached (see Figure 1). However, this method is complicated and it is difficult to change in any way the final angle of the bend. For adjustment of the angle a major interference into the tool is necessary, resulting in an increase of the manufacturing costs and extension of the manufacturing time. Figure 2 shows the process of manufacture of the forming tool [3, 4, 5, 6, 8].

2. Execution of „traktrix" bending

To this end, we tried to find a solution gaining benefits on all those factors. Thus, we arrived at the bending method according to the "traktrix" principle. The "traktrix" curve is known from the deep drawing process [1, 2]; in this type of bending the shape of the bending mandrel is derived from the shape of the drawing ring in deep drawing. In fact, the process is actually based on "drawing" the sheet metal round the bending radius on the bending insert. The basic idea is derived from sheet metal bending for 90^{o} (see Figure 3). A sketch of 90^{o} bending of unknown author and unknown source existed.

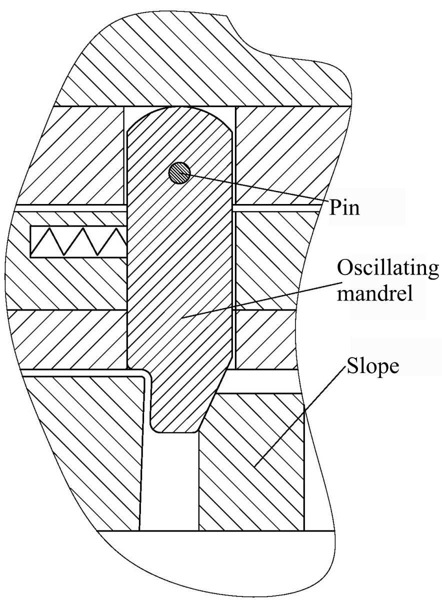

Fig. 1. Bending by oscillating mandrel

So far, the bending for angles exceeding 90^{O} has been solved with the so-called "oscillating mandrel" assuring the appropriate angle in two steps. The first step was executed by vertical motion of the mandrel, while the second step was performed with the slope and oscillating blade having oblique motion with respect to the piece in addition to vertical motion. This method is a little more difficult to realize and is more expensive. In case a correction of the product is necessary, it is still less feasible. Therefore, the proposal was made to try to reach such great bends only by vertical motion of the mandrel in two steps and by shifting one mandrel towards the other. Also a sketch of the principle of 90^{o} bending existed, with all dimensions for designing the mandrel, the bending radius, for how much to offset the point of bending etc. We decided to test in practice the principle of bending according to the "traktrix" method [1]. Thus, it was known from the very beginning that two steps of bending were to be incorporated in the tool design according to the sketch. It is a special feature of the mandrel that it consists of two different radiuses therefore it must be made by wire erosion. On the second bending insert also the withdrawal at 2^{0} angle is provided, since due to elasticity of material the piece is slightly straightened. It was assumed that the size of the angle could be set in the first stage of bending; such design should enable us to reach the angles exceeding 90^{0}; in our concrete case we needed bending for $90{,}3^{0}$.

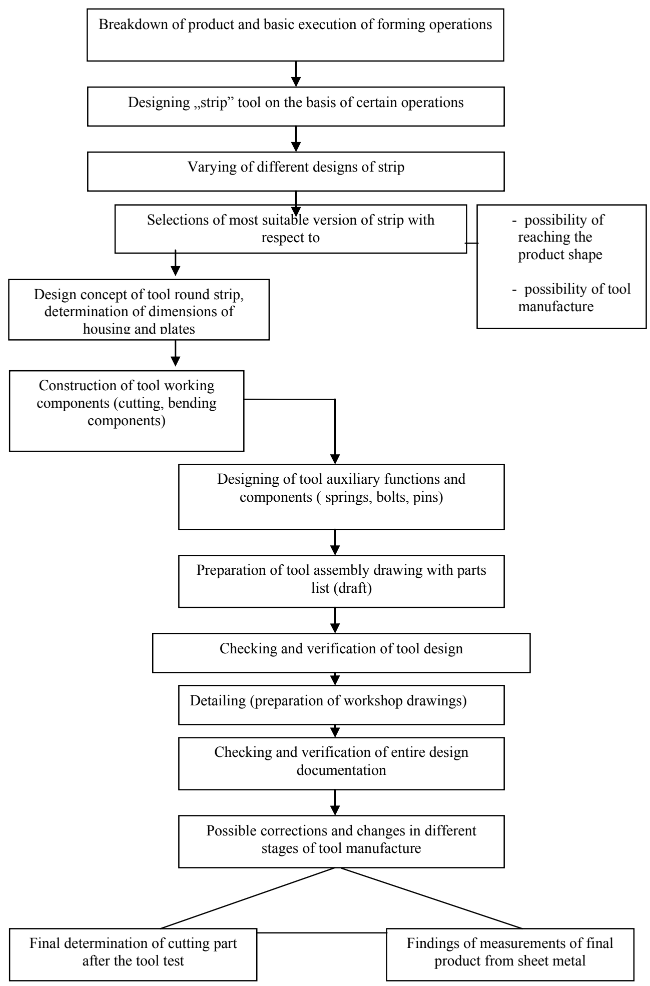

Fig. 2. Process of forming tool manufacture

3. Generation of sheet metal

Bending itself was performed according to the sketch, the only difference being in the bending angle in the first stage, since the piece was bent for more than 45^{0} (concretely for 47^{0}). It was assumed that the piece would be slightly straightened therefore it was bent for 1.7^{0} more than the theoretic value for the product.

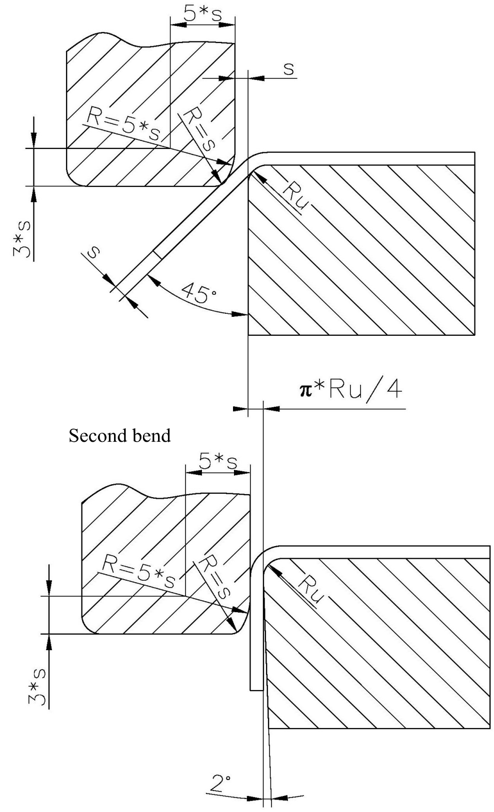

Fig. 3. Executing of 90^0 bends in two steps (mandrel according to "traktrix" shape)

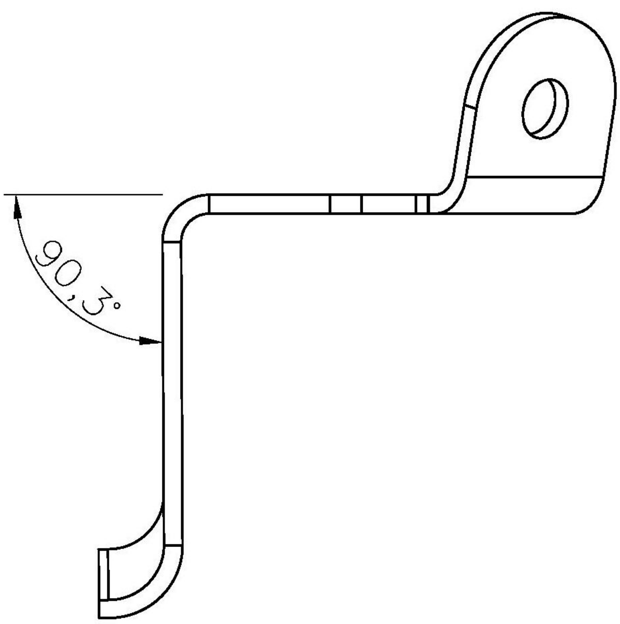

Fig. 4. Product and required bending angle

The measurement results showed that our assumptions were correct since the product was appropriate in that area already after the first tool test [7, 8].

The Figure shows all the necessary dimensions how to design the mandrel, the bending radius, for how much to offset the point of bending etc.

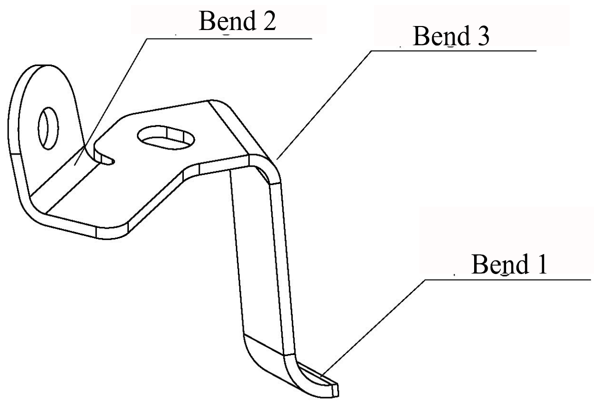

Fig. 5. Model with indicated bends

Even in the available literature it was not possible to trace anything similar in connection with bending, so we decided to use that principle in practice. Our concrete product in Figure 4 had to be bent for 90,3°.

In the cross section of sheet metal, loaded by bending, the fibres near to the centre of the curving radius contract, while on the other side they expand. In some intermediate fiber the extensibility is equal to zero and that is called the neutral line.

In the circumstances of ideal linear-plastic bending the direction of tangential stress changes in that line.

Table. 1.
Characteristics of individual bends

	Bend 1	Bend 2	Bend 3
Bending radius **r** [mm]	6	3	3
Bending angle **φ** [^{0}]	90	77,2	90,3
Sheet metal thickness **s** [mm]	2	2	2
Bend width	20	20	20

Theoretically, the radius of the neutral axis is determined according to the equation derived from the theory of plastic bending:

$$\rho = \sqrt{(r+s)\cdot r} \ \text{[mm]} \tag{1}$$

The neutral line does not run in the centre, but it is the nearer to the centre of curving radius r the smaller the ratio between the curving radius r [mm] and the sheet metal thickness s [mm] (Figure 6).

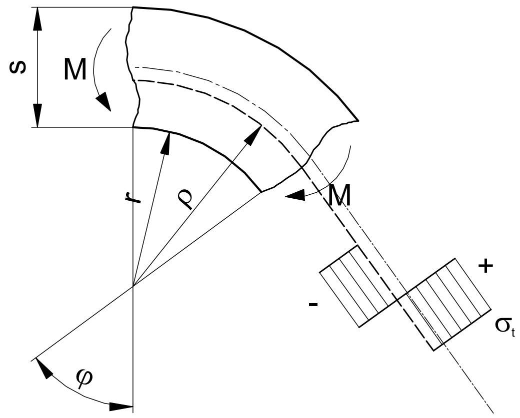

Fig. 6. Ideal plastic bending of sheet metal

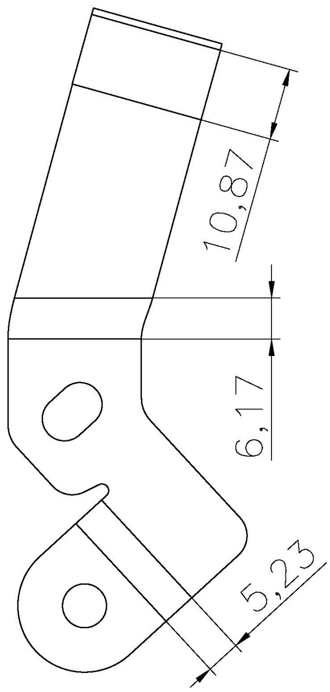

Fig . 7. Generated shape of product model

In practice the coefficient of neutral line is used for the determination of the neutral axis.

$$\xi = \frac{\rho - r}{s} \qquad (2)$$

For approximate calculation it suffices (in case of small radiuses!) to take $\xi = 0{,}33$

The length of the neutral line is calculated as follows:

$$L = \frac{\pi\varphi}{180} \cdot (r + \xi \cdot s)\,[\mathrm{mm}] \qquad (3)$$

Figure 7 shows the generated shape of the product model.

In the sketch of the "traktrix" principle it can be seen that in the first step the sheet metal is bent for about 45^0 and in the second step to the final dimension. It is important that the two bending inserts are offset for the value $\pi = R_U/4$ one in relation to the other.

That offsetting ensures the semi-finished product to be bent in the first step at the point which is "drawn" in the second step round the bending radius. In the second step it is necessary to provide still the withdrawal for the piece i. e. the negative angle on the bending insert, namely 2^0.

Table 2.
Values for generation of sheet metal

	Bend 1	Bend 2	Bend 3
Radius of neutral line **r** [mm]	6,928	3,873	3,873
Coefficient of neutral line ξ	0,646	0,436	0,436
Generated length of bend **L** [mm] – theoretical	10,88	5,218	6,11
Generated length of bend **L** [mm] – VISI progress	10,87	5,23	6,17

That with drawal is provided on the bending insert so that the piece can be bent over the required angle and returned to the correct dimension after relieving of load and elastic spring back [3]. The size of the angle is determined with bending in the first step (see Figure 3). Thus, by lifting and lowering the size of the desired angle can be adjusted faster and with minimum cost.

In the second step the mandrel is always moved over the bending radius so that in this step the angle itself is not adjusted.

In our case the piece was bent in the first step to 47^0, it slightly sprang back and in the end the piece bent to about $90.^o$ was obtained. The piece had the required dimensional tolerance already after the first tool test.

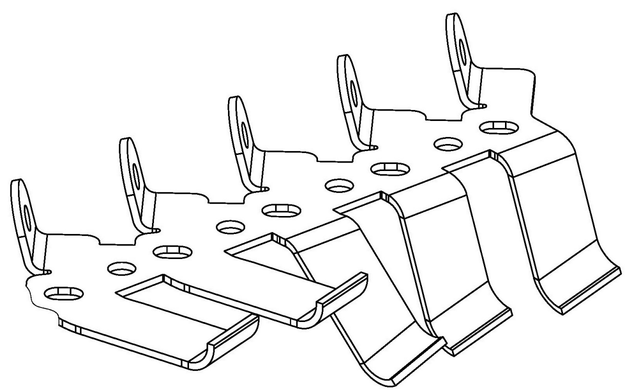

Fig. 8. Strip in 3D form

Figure 8 shows the strip in 3 D form (only the bending part of tool), where it can be seen that the angle 90.3^0 reached in two steps

4. Bending for 90° by „turning of the strip"

In practice we met still another interesting case of bending, namely bending for 90^0 in one step. That method is feasible only in some cases depending on the complication of the piece, the position of the piece in strip, the forming steps in the strip. Figure 9 shows the product and Figure 10 the strip in 3D form. The product has an impressed reinforcement to prevent major elastic spring back of the piece with only vertical motion of the mandrel.

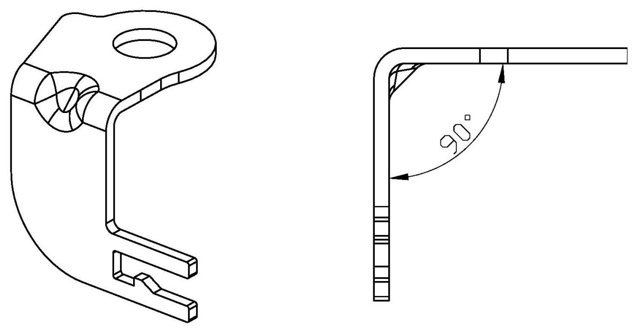

Fig. 9. Product and required bending angle

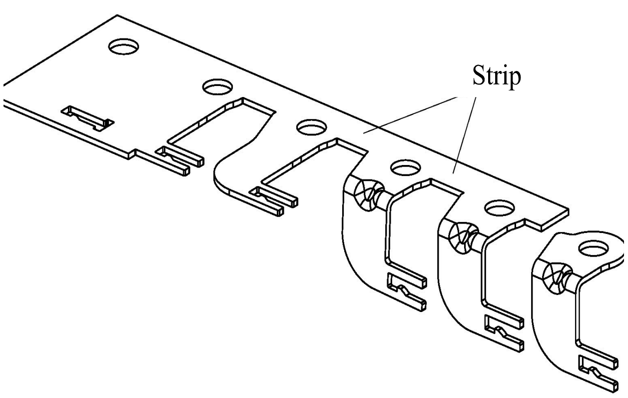

Fig. 10. The strip in 3D form

However, it could be seen already after the first tool test that the product sprang back up to 2.5^o, which already deviated from the required tolerances. Opening of the product can be solved with the use of the above mentioned "oscillating mandrel". This is an expensive solution of the problem, consuming much time, which in our concrete case was not feasible for us.

Thus we arrived at a simpler solution which was implemented within the shortest possible time. The first tool test showed for how much the product "opens"; that was a guideline to us for how much the product and/or the strap in the strip should turn (Figure 9) to obtain a dimensionally appropriate product after relieving of load. It was still necessary to verify what that turning meant for the catcher. Turning of the strap reduces the diameter of the hole and/or its rectangular projection with respect to the motion of the catcher towards the hole orto which the strip in the tool is positioned. It was found out that in case of 2^0 angle the turning causes no difficulties during strip positioning.

Thus, we modified the bending insert, the pressing plate and the bending mandrel (see Figure 11).

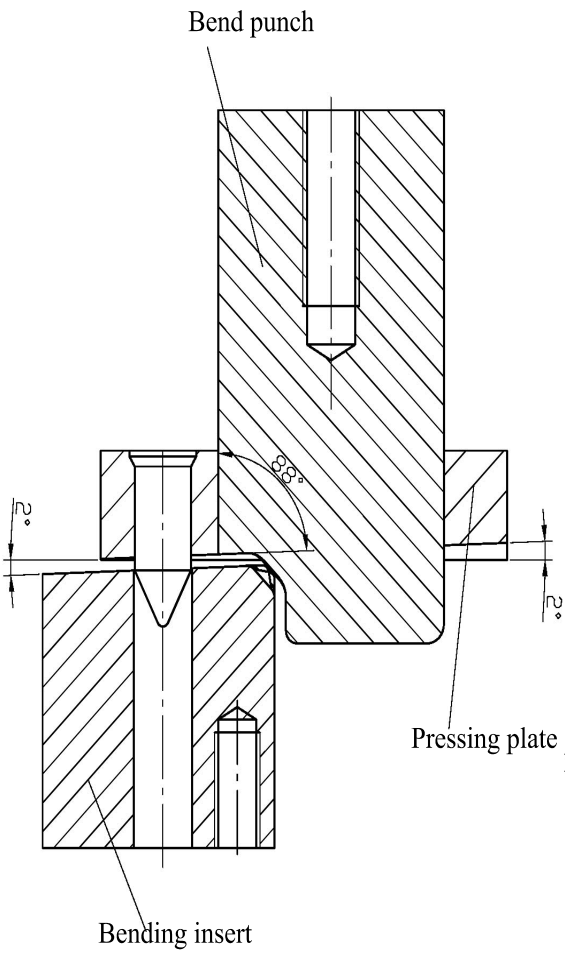

Fig. 11. Execution of 90^o bend in one step

On the bending insert we made a 2^o slope; for that approximate value the product "opened". Thus the product positioned itself so that it was theoretically bent for 92^0 by vertical motion of the mandrel. After elastic spring back the 90^o angle was reached. Beforehand, we additionally modified the pressing plate and the bending mandrel, so that the assembly matched geometrically and that the withdrawal for the bending insert and product was obtained in the pressing plate. In the next steps the strap was straightened by the pressing plate into the original horizontal position, since the product had to be still cut off, so that it could fall from the tool. The solution proved to be very efficient; the dimensionally appropriate product was obtained cheaply and faster [9, 10].

Fig. 12. 3D models of finished product

5. Conclusions

In both cases we made only one version of each method, of course for practical reasons since we did not need different angles on one product. Also from the point of view of time and costs further developing of both examples in the company was not justified, therefore it would be appropriate to complement both methods in detail theoretically and by testing in the frame of a more comprehensive seminar work or research work.

For the "traktrix" method experiments could be performed with mutual off setting of bending inserts and mandrels, it could be found out how many degrees in exicess of 90^o can be reached by this process, how the bend in the first step influences the final angle. Tables could be made for different materials, different bending radiuses, mutual offsets etc.

Often also the method with "turning of the strip" would be used, where the 90^0 angle is reached in one step only. Thus, the manufacture of another bending insert and mandrel and/or "oscillating mandrel" is avoided. In this case it is necessary to anticipate the position of the product in strip already in the designing stage so that the execution will be possible.

Nowadays, fast and simple solutions, not resulting in great costs and manufacturing time, are more and more important, since they assure competitive advantage on the increasingly demanding market and existence and development (Figure 12) .

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